JIRCAS 2005 International Symposium in Ishigaki, 117-120

Heat injury in fruit vegetables and high-temperature control technology

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There is a demand for production of temperate vegetables in the tropics and subtropics. When vegetables are grown at high temperatures, though, they experience heat stress, and high-temperature injury occurs during production. High-temperature injury can be caused by short-term stress, for example temperatures exceeding 40 °C, as well as by mild long-term or chronic heat stress. Farmers do not cultivate vegetables in areas where the crop dies at high temperatures, for example above 40 °C, but in agriculture, chronic heat stress is a problem even at temperatures slightly above optimal. In this report I describe the production of heat injury in green bean (*Phaseolus vulgaris*) under chronic mild heat stress, and high-temperature control technologies for greenhouses in summer in Japan.

1. High-temperature injury sustained by the green bean (*Phaseolus vulgaris*)

The green bean is an important and commonly-grown crop that is harvested in both the mature and immature state. The immature bean is used as a green vegetable. Many crops sustain more damage to the reproductive organs than to somatic tissue as a result of heat stress (Hall, 1992). In the green bean, high temperatures of about 30 °C during the reproductive growth stage result in loss of yield. We studied the heat-sensitive stage and the physiological changes caused by heat stress using green beans grown in a greenhouse and in the field. The pod set ratio was decreased by heat stress applied on the flowering day, 1 day before flowering and 8-11 days before flowering. The reduction of the pod set ratio by heat stress 8-11 days before flowering was traced to the occurrence of sterile pollen (Suzuki *et al., 2001a*).

Structural abnormalities of the microspore were due to tapetal degeneration. The first distinct structural abnormalities were detected in the distribution pattern of the rough endoplasmic reticulum (RER) in the tapetum at the early microspore stage under high-temperature conditions. Stacks of rough endoplasmic reticulum were frequently observed in the tapetum under optimum conditions, but these rarely occurred under high-temperature conditions. Various patterns of endoplasmic reticulum (ER) arrangements–linear, wavy, looped or circular–were observed in the tapetum. Two types of circular ER were observed at the microspore stage under high-temperature conditions: RER that had ribosomes on the surface, and smooth endoplasmic reticulum (SER) lacking ribosomes. The tapetum underwent more degenerative changes under high-temperature conditions earlier than under optimum conditions. The structural abnormalities of the microspore were associated with tapetal degeneration. We concluded that high air temperatures affect the ER structure and block its function in the tapetum, which then induces earlier-than-usual degeneration of the tapetum. Pollen sterility results from tapetal degeneration (Suzuki *et al.*, 2001b).

Anther indehiscence occurred when pollen stainability fell to below 20 % at high temperatures. Pollen tubes were stained with aniline blue to make the ovule more observable under optimum conditions, although heat treatment limited visibility. We were still able to determine that heat stress at the flowering stage blocked pollen tube elongation in the style, particularly if high temperatures occurred exactly one day before flowering (Fig. 2). Both normal pollen development in the anther and normal pollen tube elongation in the style are necessary for successful fertilization under high-temperature conditions.

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Abnormal pods occurred as a result of failure of fertilization because the pollen tubes did not reach the ovules on the peduncle side under high temperatures. Even when fertilization occurred successfully, abnormal pods appeared, with poor ovule development. Figure 1 summarizes the mechanism of appearance of high-temperature injury.

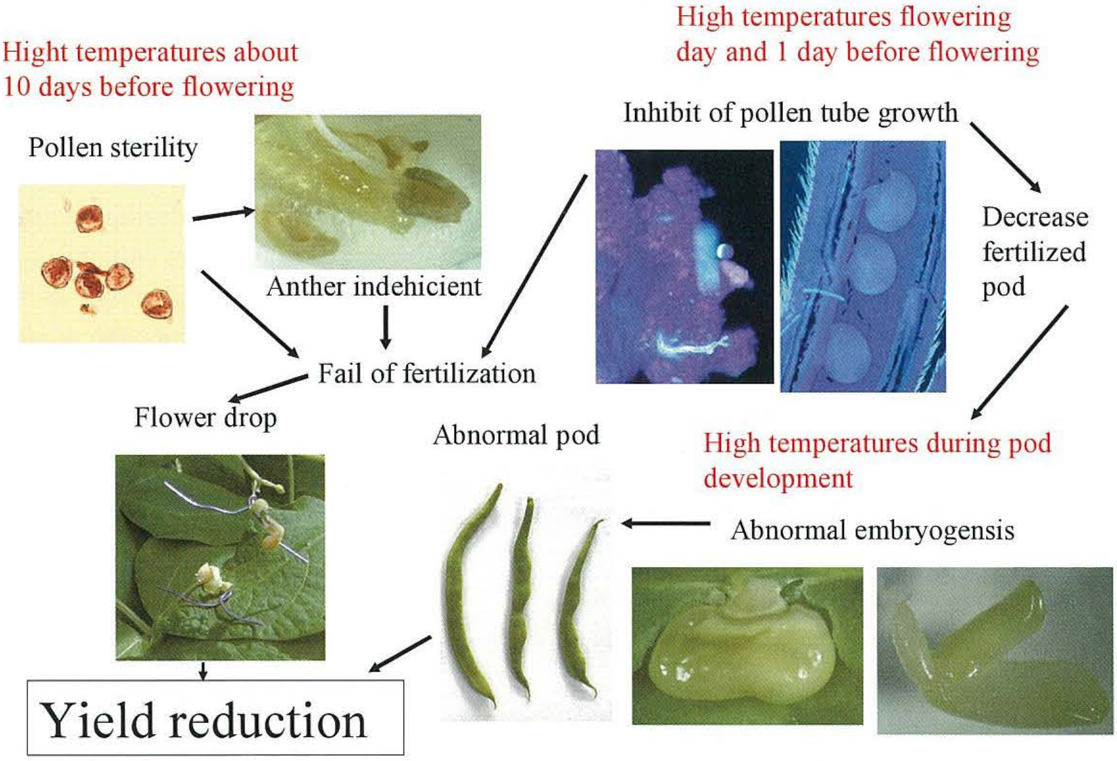

Fig. 1. Mechanism of the high temperature injury in a green bean.

2. Heat-tolerant cultivars

The average air temperature in summer in Ishigaki Island is about 28-30 °C. These temperatures are suitable for the selection of heat-tolerant strains of green bean. The heat-tolerant green bean cultivar 'Haibushi' (Fig. 2) was developed from an accession collected in southeast Asia by screening 350 breeding lines and cultivars (Nakano *et al.*, 1997). 'Haibushi' has a higher yield potential than commercial cultivars, as seen in local adaptability trials conducted in several areas in southern Japan (Nakano *et al.*, 1997).

We cultivated numerous strains and cultivars in the field. Pod yield, flower number, pollen stainability and pollen tube elongation were examined using heat-tolerant and heat-sensitive cultivars of green bean grown in the field. Heat-sensitive cultivars showed low pod yields in the summer cropping. Flower number was higher in the summer cropping than in the spring cropping. Pod set ratio decreased with increasing temperature, but it was higher in the heat-tolerant cultivars than in the heat-sensitive ones. Heat-sensitive cultivars showed low pollen stainability, and only a small number of pollen tubes were observed in the ovule. Both normal pollen development in the anther and normal pollen tube elongation in the style were necessary to set pods at high temperatures. The heat-tolerant cultivar showed a superior ability in these factors.

If a similar phenomenon occurs in other fruit vegetables, examination of pollen stainability, pollen tube elongation and appearance of abnormal pods are important factors in selecting heat-tolerant strains for production of new cultivars.

Hight -> High; High temperatures on flowering day; indehicient -> indehiscent; Fail of fertilization -> Failure of fertilization; Decrease fertilized pod -> Decreased numbers of fertilized pods; embryogensis -> embryogenesis

Fig. 2. 'Haibushi', a heat-tolerant green bean cultivar.

3. High temperature control technologies

High temperature control technologies were studied, aiming at the effective utilization of greenhouses in summer. Fog and fan cooling, fan and pad systems, roof cooling by spraying, shading with covering material, chillers, improvement of ventilation, and fully-open greenhouses are techniques used for summer temperature control in greenhouses. Some cooling technologies, like air conditioning, are very expensive. Fog and fan cooling (Fig. 3) and fan and pad systems are a type of evaporative cooling, so their effectiveness depends on ambient humidity. Shading has little effect on decreasing air temperature, but it obtains good results since it reduces light stress and decreases plant body temperature. Shading also decreases workforce discomfort. More effective covering materials that allow beneficial light through but exclude infra-red will be developed in the near future. Cultivation of green vegetables is enabled, even in the summer, by utilization of cooling water. Cooling ability and price of the equipment are the chief problems. In the case of hydroponics, high levels of dissolved oxygen in the nutrient solution are also effective in summer. Using netted frames to protect vegetables from insects is desirable in tropical and subtropical island areas. High-eaved greenhouses are advantageous for summer cultivation. Eco-physiological taints of crops under such conditions using these techniques are not clear. Research is necessary for using effective methods to produce temperate vegetables under protective horticulture in the subtropics and tropics.

It is not yet practical to lower air temperatures effectively in the field, but may become possible if greenhouse technology is improved. New technologies for decreasing air temperatures during the reproductive stage need to be developed, since yields cannot be increased by cultural practices alone. We hope that many researchers will find our reports useful when investigating the physiological phenomena associated with heat injury, and that research will advance sufficiently to enable efficient production of vegetables at high temperatures.

Fig. 3. Fog and fan cooling system.

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